ACE Clouds: Motivation and Mission Concept

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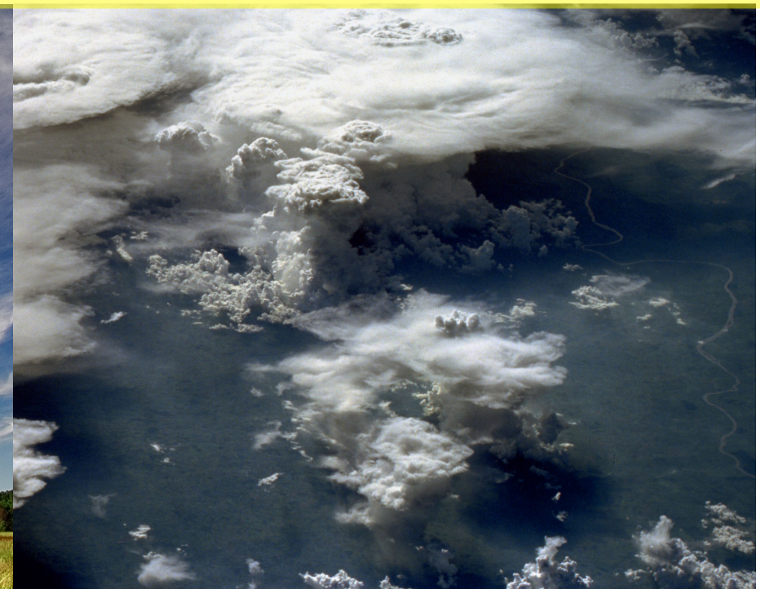
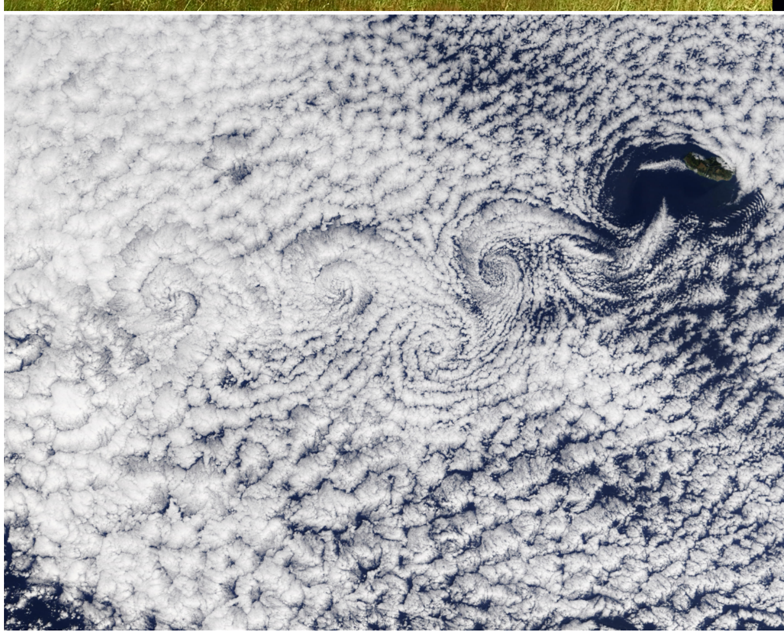
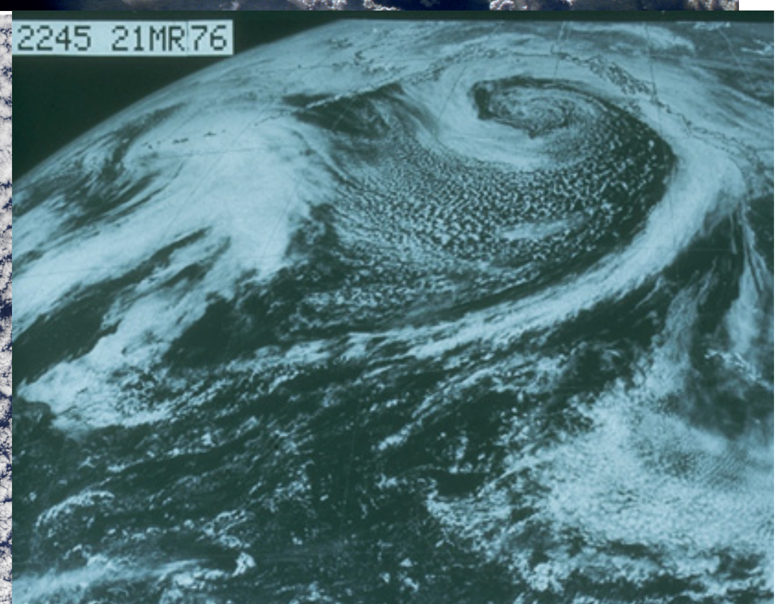
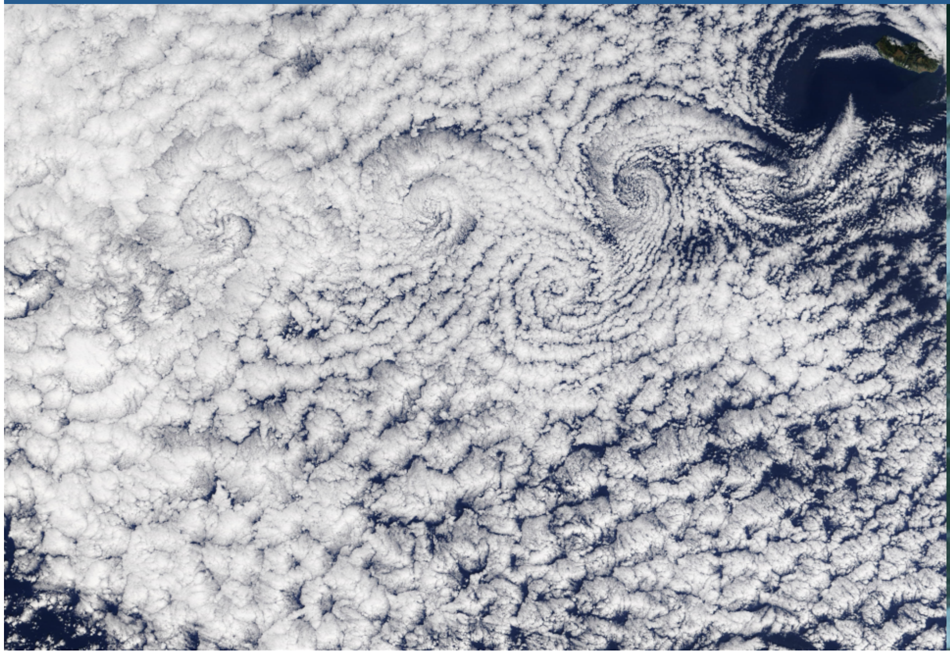
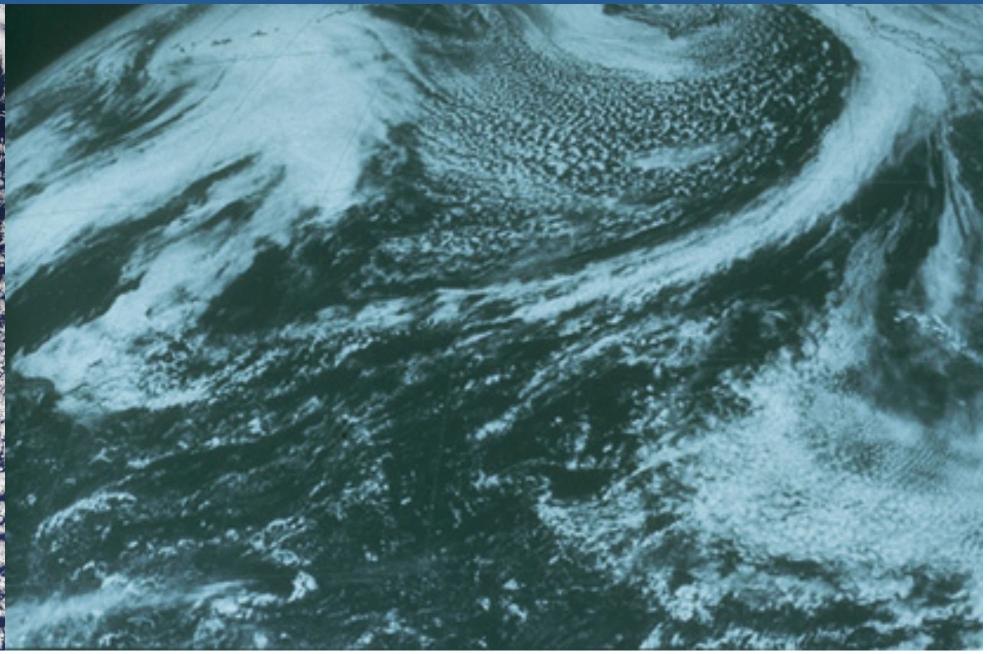
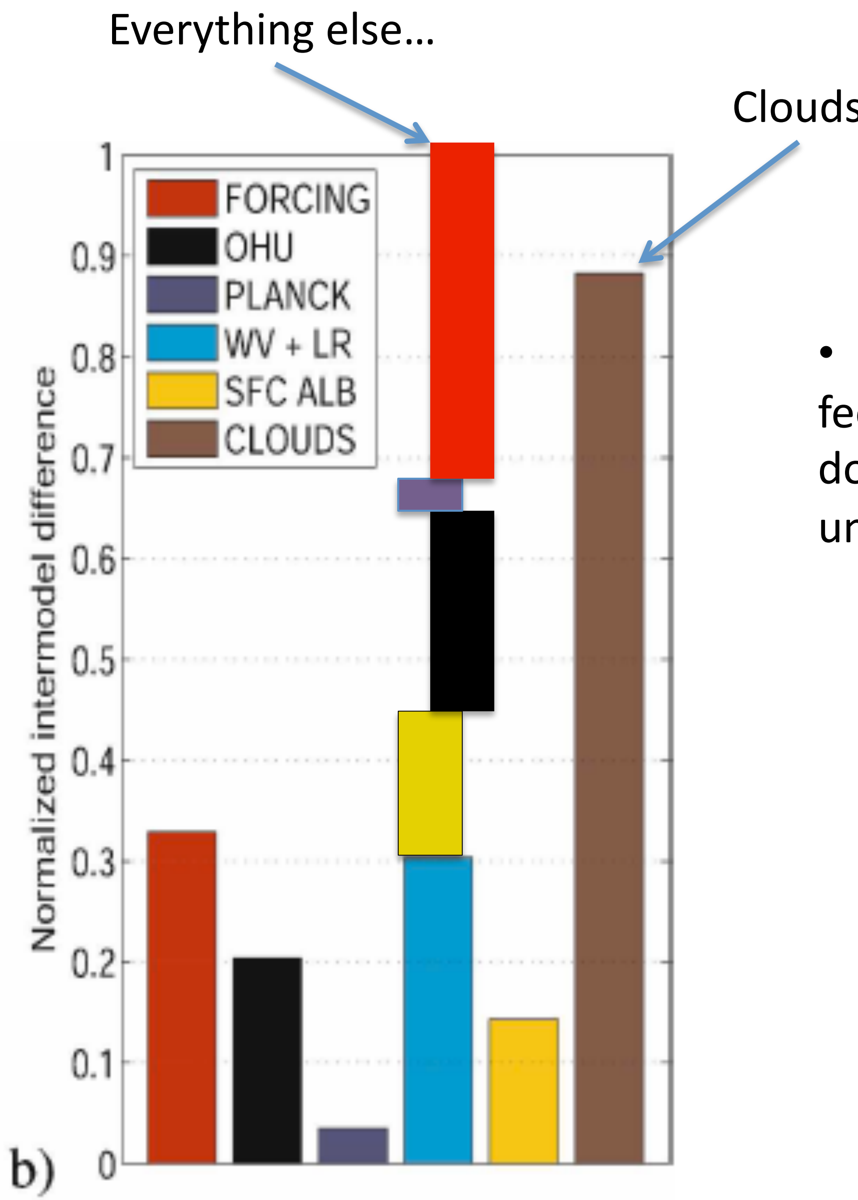




Advance our ability to observe and predict changes to the Earth's hydrological cycle and energy balance in response to climate forcings, especially those changes associated with the effects of aerosol on clouds and precipitation.





• IPCC AR4: Cloud Feedbacks **are a major source** of climate change uncertainty - both to warming and global precipitation changes.



From Dufresne and Bony (2008)

• Cloud-related feedback processes dominate these uncertainties.

So, why can't the cloud feedback problem be solved?

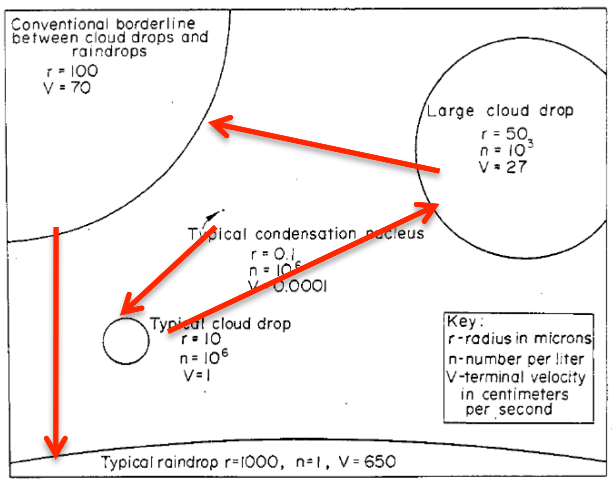
Existing measurements provide an excellent foundation from which to build, however, the problem is not solved (and shows amazingly little progress over the years). Why?

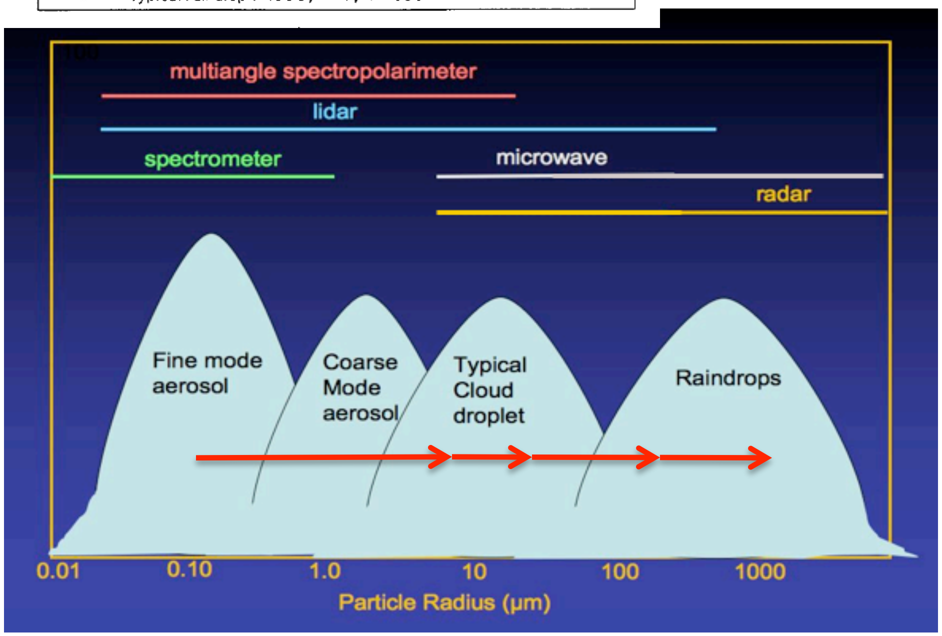
Two Fundamental Reasons...

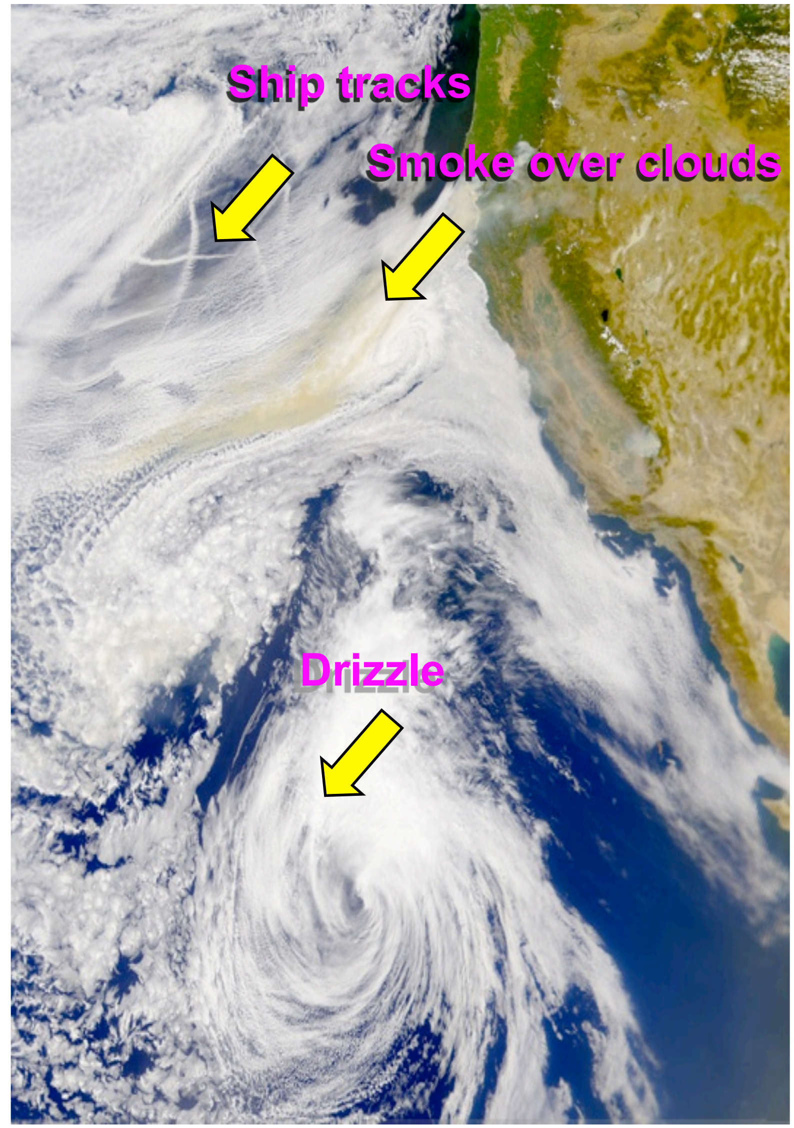
1. The problem is severely under-constrained with existing data.
2. The majority of the condensate in the atmosphere is hidden from most of our sensors

What is *the nature of the problem*? It is one of **process** – understanding processes that move water through the climate system via formation and evolution of particles.

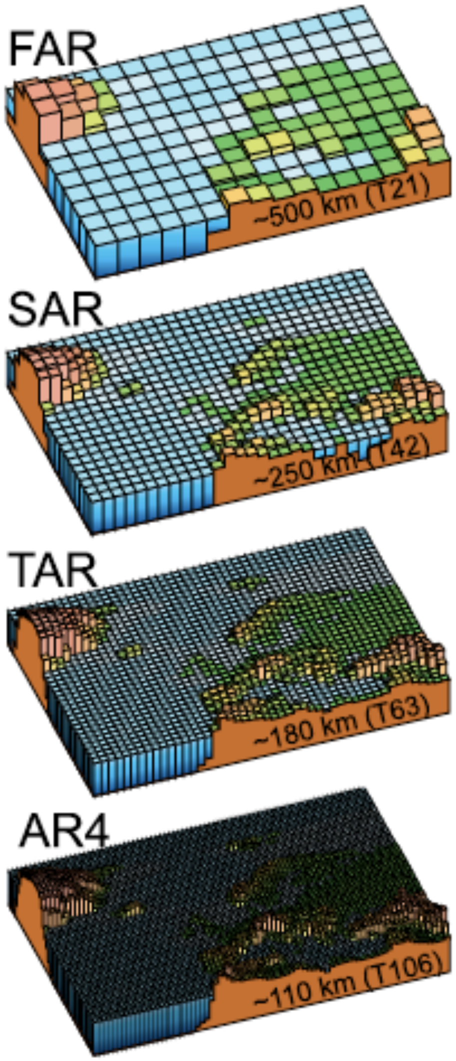
- It is the vertical profiles of particle distributions (aerosol, cloud, precip) that must be inferred by remote sensors if some *understanding of process* is to emerge.







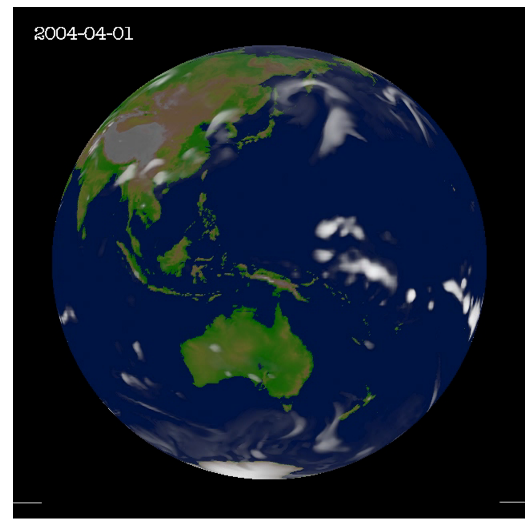
MODELS Are Evolving to Resolve Process…



Rapid pace of Model evolution

Models are evolving toward global cloud resolving models
By late 2010's, global climate models will begin to resemble global cloud resolving models

NICAM global cloud resolving model
non-hydrostatic,
~3.5km global



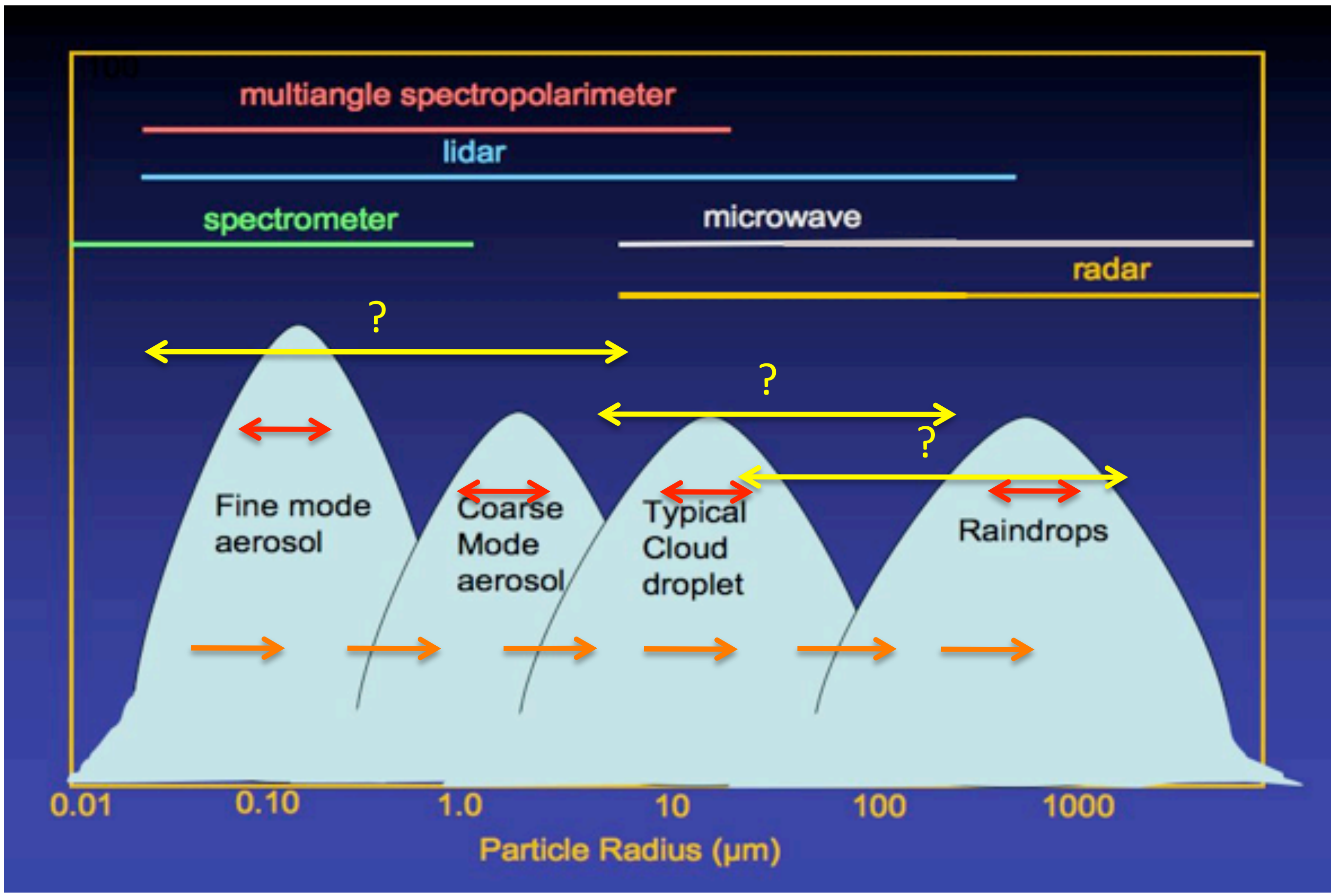
As models progress down in scale, the parameterization of *microphysical processes* increasingly becomes the weak link and global-scale observations will become increasingly important.

Evolution of our Measurement Strategy

Past (passive): Grossly characterize the bulk properties of profiles

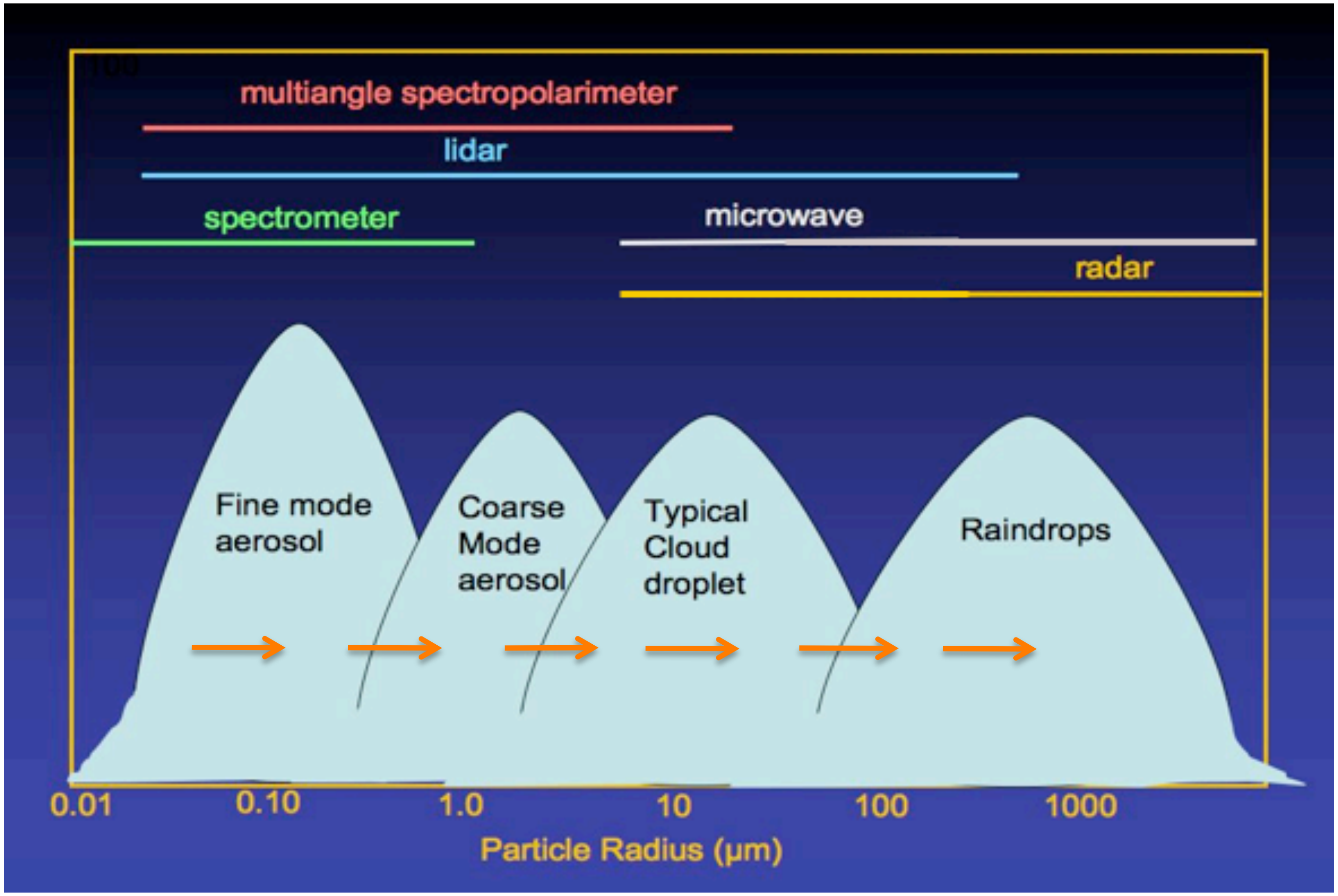
Present (A-Train): Characterize the basic profile of microphysics

Future (ACE): Characterize the processes that drive changes to particles in the column

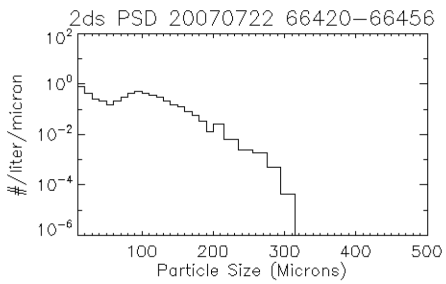


1. The problem is **severely under-constrained with existing data**. To resolve process, we need independent measurements that constrain simultaneously multiple particle modes.

Future (ACE): Characterize the processes that drive changes to particles in the column



1. The problem is severely under-constrained with existing data....



Where we have been: Capturing gross character of atmospheric columns can be done with passive only (vis, IR, Microwave)

Where we are now (A-Train): Capturing the essential cloud microphysical structure requires active measurements (combined with passive) that can penetrate optically thick clouds

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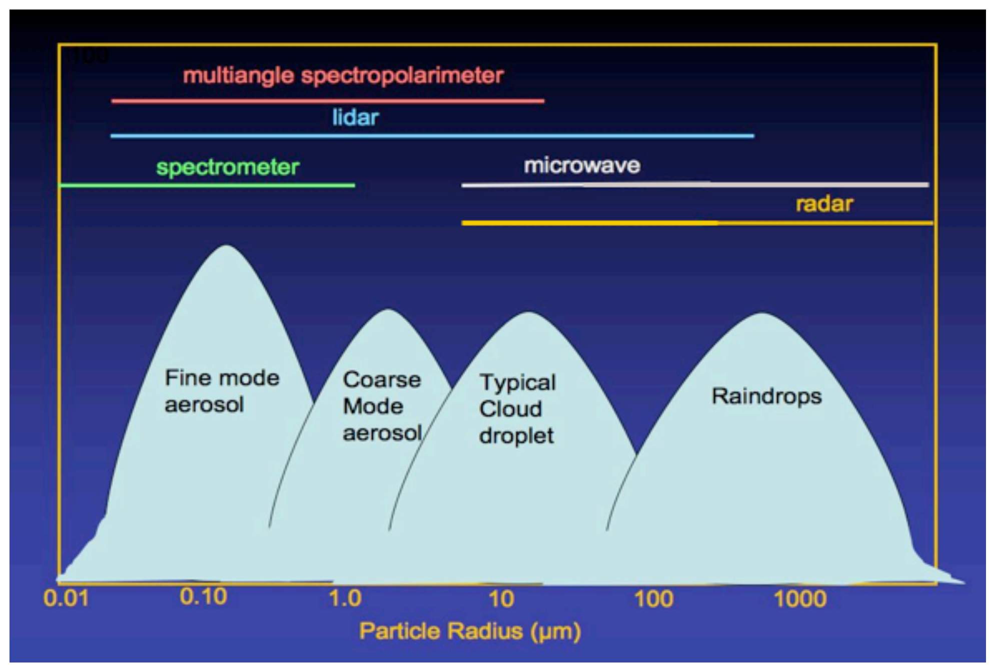
However, resolving structure does not imply resolving process…

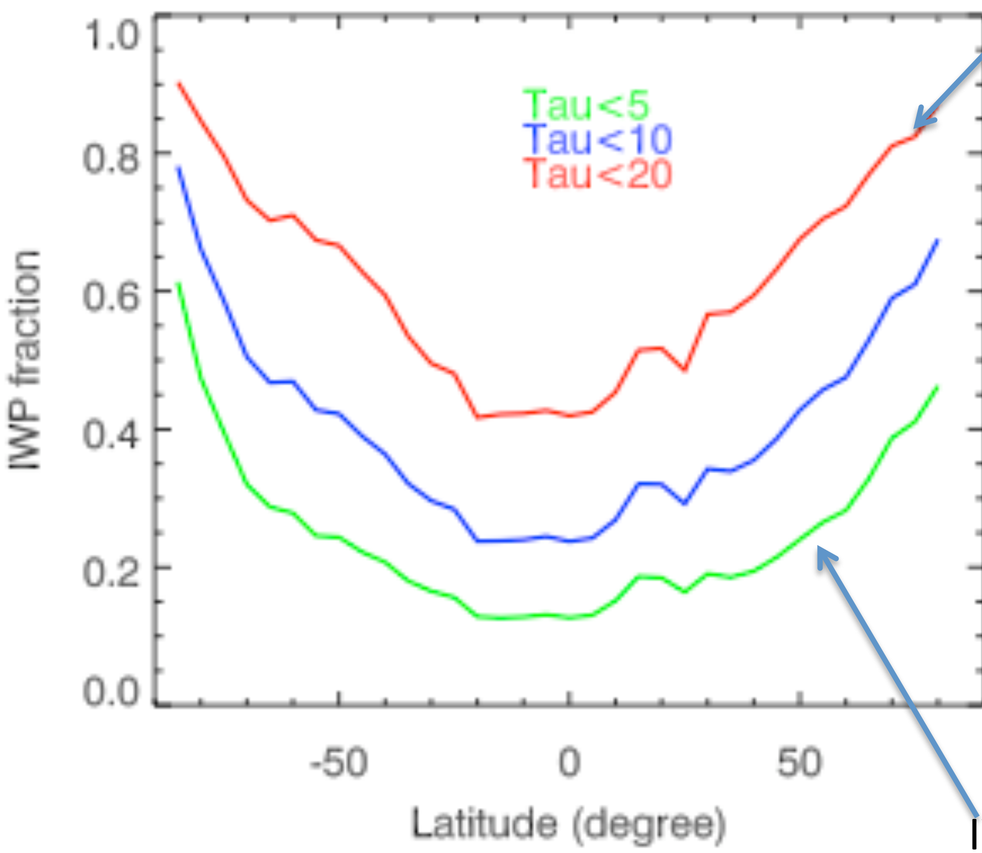
Where we need to be (ACE): Resolving process requires vertically resolved, multiple, **independent parameters** that are sensitive to specific processes.



2. The majority of the condensate in the atmosphere is **invisible** to passive sensors

The majority (>50% in the tropics and >20% in the midlatitudes) of condensed water is effectively **hidden** from visible and IR sensors – i.e. completely obscured by overlying condensate. Nearly 100% of ice is hidden from passive microwave.

IWP Fraction Accessible to Vis Sensors



Implications…

1. Gross properties are uncertain
2. Bulk microphysics are beyond reach
3. Processes are impossible

Post A-Train, Passive sensors alone ***WILL NOT*** contribute meaningfully to model development.

IWP Fraction Accessible to IR Sensors

So, why hasn't the cloud process/feedback problem be solved?

The sensors we have flown are sensitive to **only the 2nd moment** of some vertically weighted integral of the vertically varying PSD.

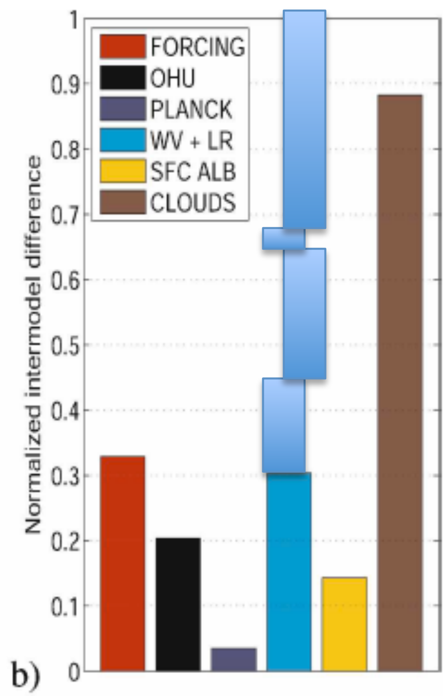
The majority of condensed water **is effectively invisible** to spaceborne solar and IR radiometers.

Present Situation: The problem is severely under-constrained and will not be solved with existing data sets.

To infer the processes important to the cycling of water through the climate system, measurements must be able to sense the vertical structure of independent parameters sensitive to particle evolution.

So....

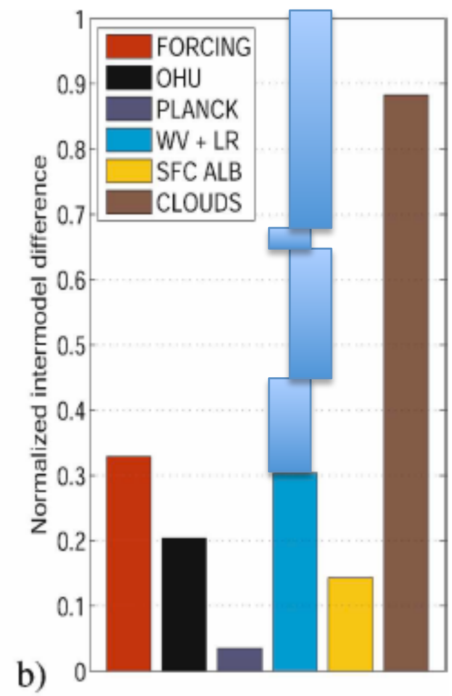
Climate Prediction Uncertainty in **2008** is overwhelmingly due to clouds....



From Dufresne and Bony (2008)

Without ACE....

Climate Prediction Uncertainty in **2038** is overwhelmingly due to clouds....



Our goal has been to look at the problem, the potential of technology, and devise a mission that can actually accomplish a meaningful goal – to create a data set that can be used to solve the the cloud feedback problem in GCMs.

ACE Clouds STM – Overall Approach

Approach: Define Cloud System-Specific Science Questions that will advance the science of the early '20's.

Then determine what geophysical parameters (at what resolution and error tolerances) are needed to address a question.

What ***combination of measurements*** (within reasonable technological limitations) would provide the geophysical parameters via retrieval algorithms?

What are the requirements of measurements to achieve science?

Sample of Cloud/Aerosol/Precip process-specific science questions

- Cirrus (morphology) - How is the role of cirrus in the water budget of the upper troposphere shaped by the dynamical and thermodynamical settings in which the clouds form?

- Deep Convection (microphysics) – What are the essential cloud radiative feedbacks on tropical convection and how are these feedbacks influenced by ice microphysics?

- Boundary Layer (Aerosol-Cloud Interaction) - How do aerosols affect the initiation and occurrence of drizzle and precipitation in boundary-layer clouds?

- Frontal Clouds (Energetics) – What role does the seasonal cycle of middle latitude cloud radiative forcing play in the poleward transport of sensible heat and how is this radiative forcing partitioned between cloud types such as cirrus, nimbostratus, etc.?

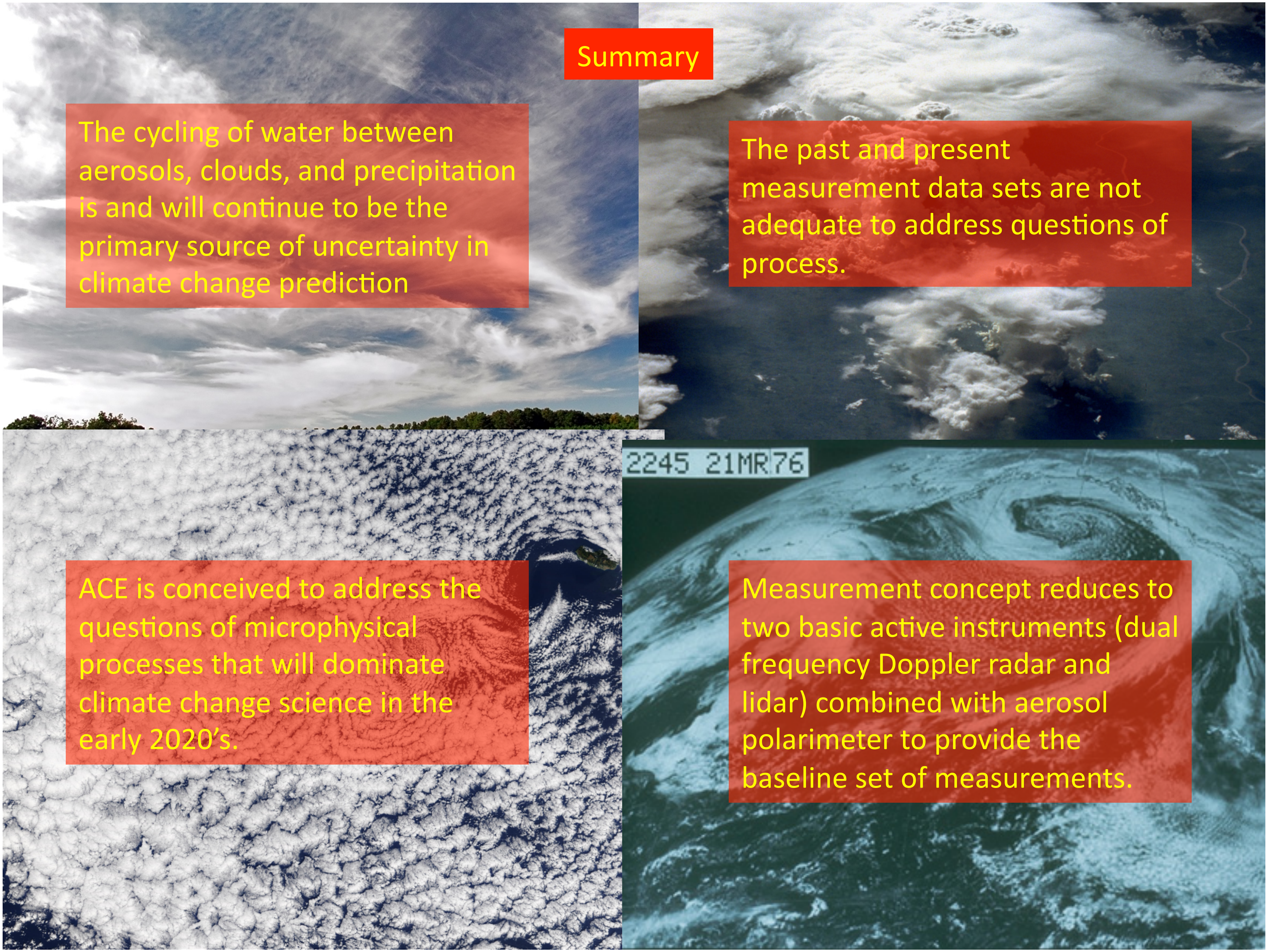
Geophysical Parameters Required to Address Science Questions

	Parameter	Specification
Morphology	1. Cloud Layer Detection	2%
	2. Cloud Top Height	250m (R), 100 m (G)
	3. Cloud Base Height	250m (R), 100 m (G)
	4. Cloud Top Phase	5%
	5. Precipitation Detection	10%
	6. Vertical Motion	
	7. Multilayer Cloud Detection	5%
	8. Cloud Phase Profile	20%
	9. Precipitation Profile	10%
Microphysics and Aerosol	10. Water Content Profile	10-25%
	11. Cloud Water Path	10%
	12. Cloud Particle Size Profile	10-25%
	13. Precipitation Particle Size Profile	10%
	14. Precipitation Rate Profile	20-50%
Energetics	15. Cloud Column Optical Depth	10%
	16. Layer Effective Radius	10%
	17. Extinction Profile	5%
	18. Radiative Effect	10% or 25 W m^{-2}
	19. Latent Heating	5 K day^{-1} km^{-1}

R: Required
G: Goal

ACE Clouds Instrument Requirements/Goals

Instrument	Measurement	Microphysical Constraint
Dual Frequency Radar (Requirement)	Radar Reflectivity Doppler Velocity Path Integrated Attenuation	6^{th} moment of cloud drop size distribution Distinguishes Cloud from Precip $2^{nd}/3^{rd}$ moment of drop size distribution (weighted by 94 GHz reflectivity). Column Liquid and Drop sizes due to differential attenuation
High Spectral Resolution Lidar (Requirement)	Cloud and Aerosol Extinction	2^{nd} moment of cloud drop and aerosol size distribution Aerosol Cloud Interactions
Aerosol/Cloud Polarimeter (Requirement)	Reflectances (some polarized) at multiple view angles.	Cloud phase, particle size, 2^{nd} moment of drop size distribution near cloud top Radiative-effective ice cloud-habit near "cloud top". Combined with Active measurements to contribute to profile properties of cloud and aerosol properties.
Microwave Radiometer (Goal)	Microwave brightness temperatures	Column liquid water path Surface precipitation rate Powerful passive constraint when combined with radar
Sub-mm Radiometer (Goal)	Brightness temperature	Column ice and size constraint for ice clouds. Powerful passive constraint when combined with radar
Infrared Radiometer (Goal)	Multispectral Infrared - radiances	Infrared emission; related to cloud temperature (altitude), phase, and particle size (near cloud top). Powerful passive constraint when combined with Lidar and Radar for night time measurements.


Summary
The cycling of water between aerosols, clouds, and precipitation is and will continue to be the primary source of uncertainty in climate change prediction
The past and present measurement data sets are not adequate to address questions of process.
2245 21MR76
ACE is conceived to address the questions of microphysical processes that will dominate climate change science in the early 2020’s.
Measurement concept reduces to two basic active instruments (dual frequency Doppler radar and lidar) combined with aerosol polarimeter to provide the baseline set of measurements.

Extras

Table 2.1 ACE Cloud Science Traceability Matrix

Category	Topical Themes
Morphology	Occurrence and macroscale structure (vertical and horizontal) of clouds and precipitation and interaction with large-scale meteorological and thermodynamic forcing.
Microphysics	Microphysical Processes that form, maintain, and cause changes to profiles of aerosol, clouds, precipitation and the interactions between them.
Aerosol	The specific role of aerosol in modifying the occurrence and properties of clouds and precipitation.
Energetics	Maintenance of and changes to the energetic balance of the atmosphere and earth system due aerosol, clouds, and precipitation.

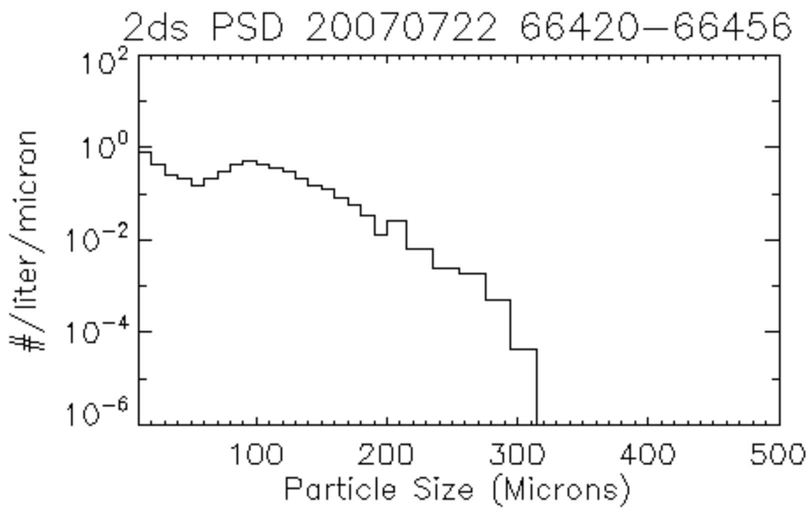
Geophysical Parameters and Error Tolerance Requirements[1]

		Narrow Nadir Swath	Wide Swath
Morphology	1. Cloud Layer Detection	2%	5% (optical depth > 0.3)
	2. Cloud Top Height	250m (R), 100 m (G)	1500 m (ice) 1000 m (liq)
	3. Cloud Base Height	250m (R), 100 m (G)	
	4. Cloud Top Phase	5%	20%
	5. Precipitation Detection	10%	20%
	6. Vertical Motion		
	7. Multilayer Cloud Detection	5%	Detection of cirrus (τ~0.3–7 depending on geometry) over lower water cloud
	8. Cloud Phase Profile	20%	
	9. Precipitation Profile	10%	
Microphysics and Aerosol	10. Water Content Profile	10-25%	
	11. Cloud Water Path	10%	25%
	12. Cloud Particle Size Profile	10-25%	
	13. Precipitation Particle Size Profile	10%	
	14. Precipitation Rate Profile	20-50%	
Energetics	15. Cloud Column Optical Depth	10%	20%
	16. Layer Effective Radius	10%	20% (liq) 30% (ice)
	17. Extinction Profile	5%	
	18. Radiative Effect	10% or 25 W m^{-2}	10 W m^{-2} (TOA)
	19. Latent Heating	5 K day^{-1} km^{-1}	

Measurement and Instrument Requirements[2]

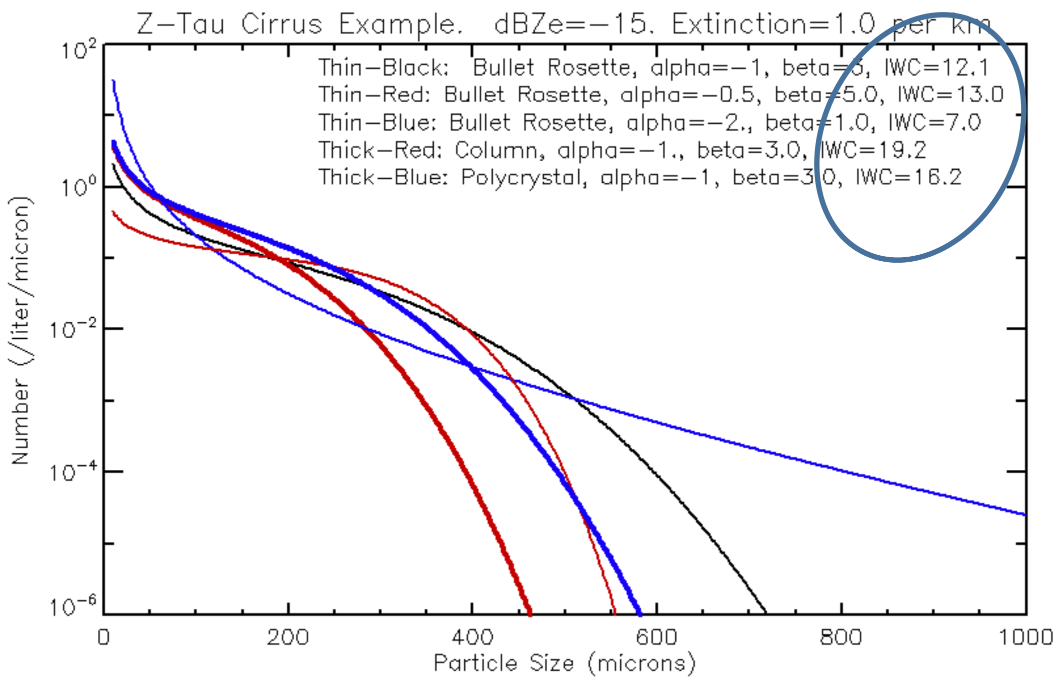
1. **W Band Radar (Table 5.1) (1-19)**
2. **Ka Band Radar (Table 5.1) (1,2,3,5,7,9,10,11,14,19,20)**
3. **High Spectral Res. Lidar (Table 5.2) (1,2,4,7,10,12,17,15,20)**
4. **High-Resolution VIS-SWIR Imager (Table 5.3) (primary =1,2,11,15,16,18; assist = 10, 12, 17)**
5. **Wide Swath Vis-IR Imager (Table 5.3), (primary = 1,4,7,11,12** 1,2,4,7,11,15,16,18; **assist =** 10, 12, 17)
6. **Low Freq. Microwave (Table 5.4) (5,10,11,12,13,14,16,19,** 5,11**)**
7. **High Freq. Microwave (Table 5.5) (10,11,12,13,** 11, 16)

Real Cirrus PSD from TC4

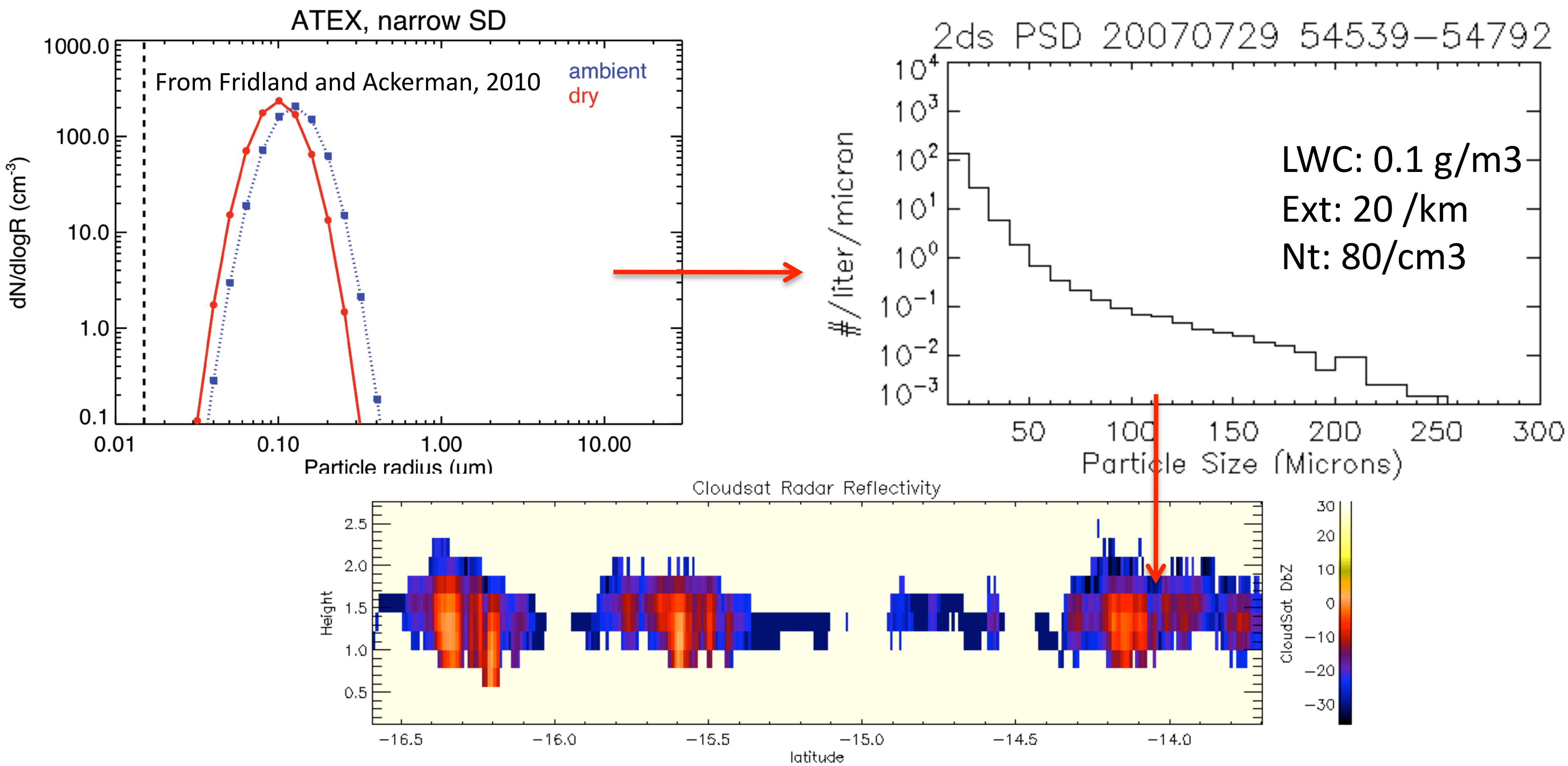


With fixed dBZ (-15) and extinction (1/km), the IWC can vary by a factor 3!

4-parameter theoretical cirrus PSD



1. The problem is severely under-constrained with existing data….



ACE Clouds Near-Term Research Goals:

Important to recognize that operational algorithms to derive aerosol, cloud, and precipitation property profiles from multiple combined active and passive instruments exist do not exist.

For ACE goals to be met, investment in algorithm development in the immediate several years is necessary.

Critical Activities:

1. Development of ACE Suborbital Instruments with more sensitivity and capability than the flight models to fly as a package on ER2 or Global Hawk – 1) dual frequency scanning radar, 2) HSRL Lidar, 3) Imaging Polarimeter, 4) Microwave radiometer, 5) Sub-mm radiometer, 6) Thermal IR Imager

2. Creation of instrument simulator codes and forward models that can operate within detailed atmospheric models so that retrieval algorithms can be developed and validated within controlled situations

3. Creation of data sets with ACE suborbital instruments to test and validate emerging ACE algorithms.
    - Series of biannual suborbital deployments to sample cloud systems of increasing complexity with ACE suborbital instrument package and in situ aircraft.

4. Focused analysis of existing NASA data sets (i.e. TC4 and Crystal FACE) that have ACE-like active (radar and lidar) and passive measurements with coincident in situ validation.